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Single Electron-Hole Pair Generation using Dark-Bright Solitons Conversion Control

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Abstract

In this paper, we present the new concept of single electron-hole pair generation by using dark-bright solitons conversion control based on microring resonator coupled to one arm MZI. By using some suitable parameters and found that the single electron-hole pair are seen, therefore, the single electron-hole pair generate can be storage and controll within the design system.

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Keywords: single electron-hole pair generation, dark-bright solitons conversion control

1. Introduction

Recently, the electron-hole pair generated in 1.06- μm separate-absorber-avalanche (multiplier) InP-based devices [1], SiGe/Si planar waveguides [2] fabricated with a Ge concentration ranging from 2% to 6% and different thicknesses ranging from 200 nm to 2 μm , generating electron-hole pairs with a 100 fs laser pulse emitted at 810 nm, and monitoring the free-carrier absorption transient with a c.w. probe beam at 1.55 μm , bipolar transistors [3], CMOS process [4], InAs-GaSb superlattice (SL) photodiodes [5], resonant microcavity [6], A cavity-QED using a single InAs quantum dot and a high-Q whispering gallery mode [7].

The propose of this paper is to investigate the single electron-hole pair manipulation using dark-bright solitons conversion controlled in nanoring resonator coupled to one arm of Mach-Zehnder Interferometer (MZI) as show in Fig. 1. For single electron-hole pair are placed by dark-bright solitons conversion proposed.

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2. Theory

Dark and bright solitons are the short optical pulses that can propagate into the optical medium for long period of time due to their nonlinear properties, for instance, self phase and cross phase modulations. The lack of phase with $(\pi/2)$ between dark and bright solitons can be used to form the orthogonal photon components (entangled photon). Here, the proposed model for single electron-hole pair generation system using dark-bright soliton conversion is as shown in Fig. 1. Single electron-hole pair can be generated by dark-bright optical soliton conversion within the system, in which the zero logical state $|0\rangle$ (or dark soliton input pulse: $|h\rangle$) and the logical one $|1\rangle$ (bright soliton input pulse: $|e\rangle$) are encoded into MZI. The random states between dark and bright solitons can be established within the photonic circuit, in which the output of the orthogonal states can be randomly detected via the MZI output ports.

When the dark and bright soliton pulses are generated and input into the system, the optical fields propagate through the photonic circuit are expressed by Eqs. (1) – (3).

$$\begin{aligned} E_{11} &= \frac{1}{2} In + j \frac{1}{2} A \\ E_{21} &= \frac{1}{2} A + j \frac{1}{2} In \end{aligned} \quad (1)$$

$$\begin{aligned} E_{12} &= E_{11} \left\{ (1-\gamma)^{1/2} \left[\frac{(1-\kappa)^{1/2} - (1-\gamma)^{1/2} e^{-\frac{\alpha}{2} L - j k_n L}}{1 - (1-\gamma)^{1/2} (1-\kappa)^{1/2} e^{-\frac{\alpha}{2} L - j k_n L}} \right] \right\} \\ E_{22} &= E_{21} e^{-\frac{\alpha}{2} L} \end{aligned} \quad (2)$$

$$\begin{aligned} Th &= \frac{1}{2} E_{12} + j \frac{1}{2} E_{22} \\ Drop &= \frac{1}{2} E_{22} + j \frac{1}{2} E_{12} \end{aligned} \quad (3)$$

where In is an input field, A is an added field (control), E11 and E21 are fields splitted into two arm of MZI passes through the first coupler as shown in Fig. 1, E12 and E22 are fields before merge into the second coupler, γ is the coupler loss, κ is coupling coefficient, α is the attenuated of microring resonator, $L = 2\pi R$ where R is radius of microring resonator, $k_n = 2\pi/\lambda$ is the wave propagation number in a circuit. Th is an output field and Drop is the output field signals of single electron-hole pair. L1 is a lower MZI arm, with length $8\mu\text{m}$.

We are looking for a stationary dark soliton pulse, which is introduced into the MZI as shown in Fig. 1. The input optical field (Ein) of the dark soliton pulse input and the add optical field (Eadd) of the bright soliton pulse at A port are given by

$$\begin{aligned} E_{in}(t) &= A \tanh \left[\frac{T}{T_0} \right] \exp \left[\left(\frac{z}{2LD} \right) - i\omega_0 t \right], \\ E_{add}(t) &= A \operatorname{sech} \left[\frac{T}{T_0} \right] \exp \left[\left(\frac{z}{2LD} \right) - i\omega_0 t \right], \end{aligned} \quad (4)$$

where A and z are the optical field amplitude and propagation distance, respectively. T is a soliton pulse propagation time in a frame moving at the group velocity, $T = t - \beta_1^* z$, where β_1 and β_2 are the coefficients of the linear and second-order terms of Taylor expansion of the propagation constant. $LD = T_0^2 / |\beta_2|$ is the dispersion length of the soliton pulse. T_0 in equation is a soliton pulse propagation time at initial input (or soliton pulse width), where t is the soliton phase shift time, and the frequency shift of the soliton is ω_0 . This solution describes a pulse that keeps its temporal width invariance as it propagates, and thus is called a temporal soliton. When a soliton peak intensity $\left(|\beta_2 / \Gamma T_0^2| \right)$ is given, then T_0 is known.

3. Results and Discussion

When In field of dark soliton $|h\rangle$ or bright soliton $|e\rangle$ are input into the In and A ports, the input fields are combined and split into two parts with the same amount via a 3dB coupler (50:50), which they are E11 and E12. The field E12 is the output field of E11 which generate in microring resonator controlled phase shifted device. Finally, the fields are combined again at the second 3dB coupler, in which the random combination of the orthogonal pulses (electron-hole pair) can be obtained via the MZI ports as shown in Figs. 2-5. Fig. 2 shows the single electron-hole pair manipulation generated by using dark-dark solitons (h-h) input in In and A ports which can be measure h-h conversed as shown in Fig. 2(a) and we found that the single electron-hole pair manipulation are seen in Th and Drop port as shown in Fig. 2(b), respectively. When using dark-bright solitons (h-e) input in In and A ports and we found that the electron only manipulation are seen in Th and Drop port as shown in Fig. 3(b), respectively. And using bright-dark solitons (e-h) input in In and A ports and we found that the hole only manipulation are seen in Th and Drop port as shown in Fig. 4(b), respectively. Similarly, when using bright-bright solitons (e-e) input in In and A ports which can be measure e-e conversed as shown in Fig. 5(a) and we found that the single electron-hole pair manipulation are seen in Drop and Th port as shown in Fig. 5(b), respectively. The switching time for the single electron-hole pair manipulation generation when using h-e and e-h input (in Fig 6(b) and (c)) the switching time is differenced seen (difference delay), whereas, when using h-h and e-e input as shown in Fig. 6(a) and 6(d), the switching time are same.

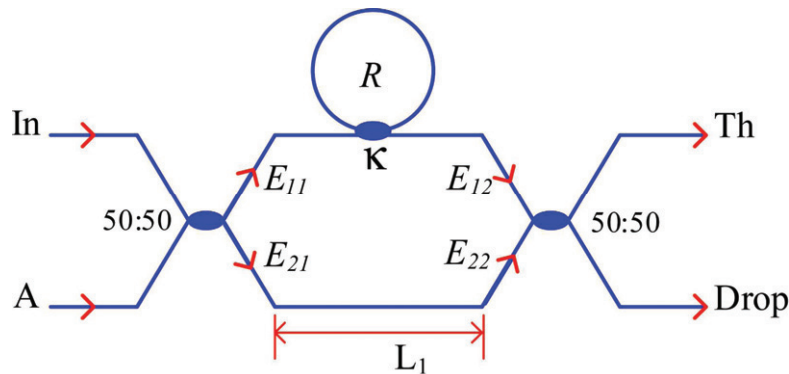


Fig. 1 Scheme of microring resonator coupled to MZI for single electron-hole pair generation

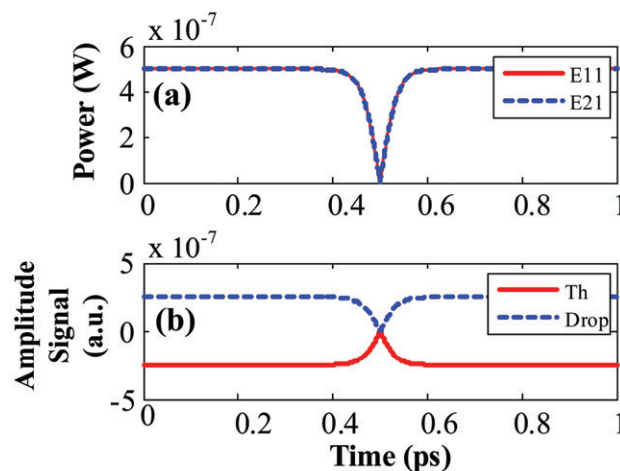


Fig. 2 Single electron-hole pair manipulation for h-h input

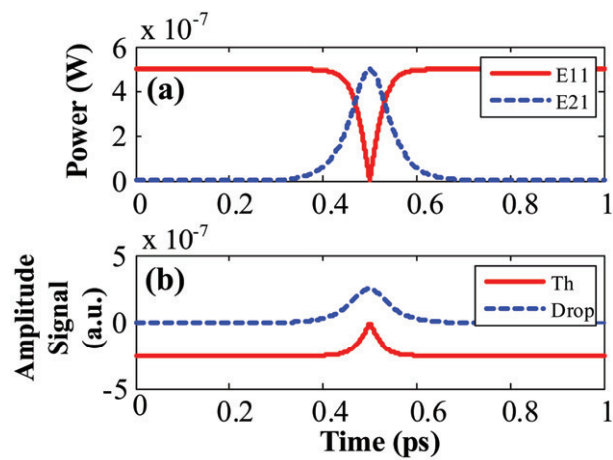


Fig. 3 Single electron-hole pair manipulation for h-e input

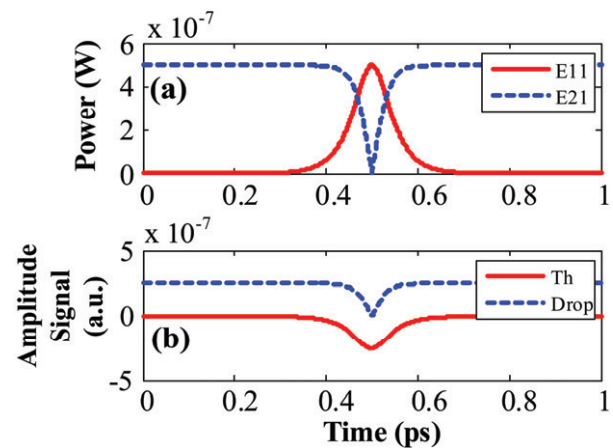


Fig. 4 Single electron-hole pair manipulation for e-h input

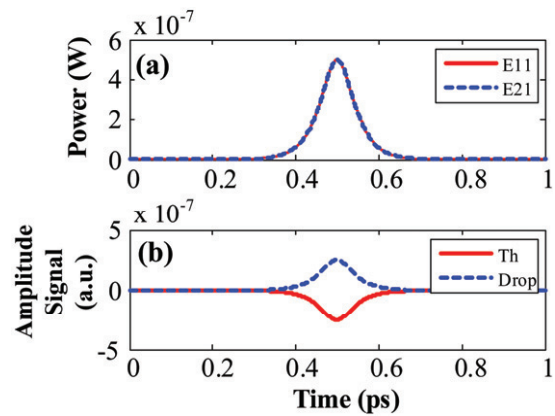


Fig. 5 Single electron-hole pair manipulation for e-e input

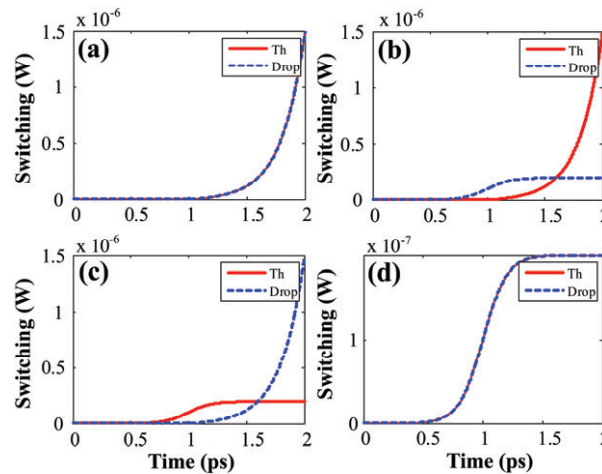


Fig. 6 Switching time of electron-hole pair manipulation using solitons input are (a) h-h, (b) h-e, (c) e-h, and (d) e-e, respectively

4. Conclusion

In conclusion, this scheme can simply be ultrafast for single electron-hole pair manipulation using dark-bright solitons conversion controlled. We found that the number of ASK enhanced peak is increased more than number of nonlinear microring resonator. In order to generate three amplitude levels, in which all nonlinear microring resonators are modulated simultaneously. As seen in Figs. 3 and 4, when TR is in resonance, a “1” is generated, when one is off-resonance, a “0” is generated. Therefore, it is observed that with TR, it is possible to generate up to three different amplitude levels by an optical device. In conclusion, this scheme can simply be scaled up to more logic levels by adding additional nonlinear microring resonators and splitters to the system.

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